iMachine: Measuring Manual Wheelchair Mass Properties

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Introduction

• Mass properties are important parameters in dynamic systems analysis, but may be difficult to estimate for irregularly-shaped objects

• Specifically, the iMachine is designed to analyze manual wheelchairs in an effort to determine the propulsion efficiency using the Anatomical Model Propulsion System (AMPS)

Objectives

• Design a spring-loaded oscillating platform to accurately measure the following parameters:

  • Single-axis moment of inertia

  • Location of the center of mass

  • Total mass

• Analyze the error and reliability of results

Methods

Hardware

• LabJack U6 DAQ device

• Optical Encoder (US Digital, E3 series), 2500 CPR

• Load Cells (Omega, LCGB series), 250 lb capacity

Software

• NI Labview v. 8.5.1

• Pro/Engineer

Static Analysis

• Record the total system mass using the summation of load cell measurements

• Locate the center of mass and reposition the object until the parallel-axis terms in inertia analysis become negligible

Dynamic Analysis

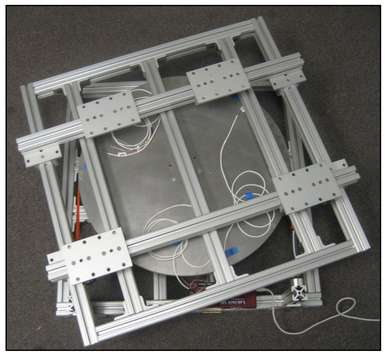
• Release the platform from rest at an initial angular displacement

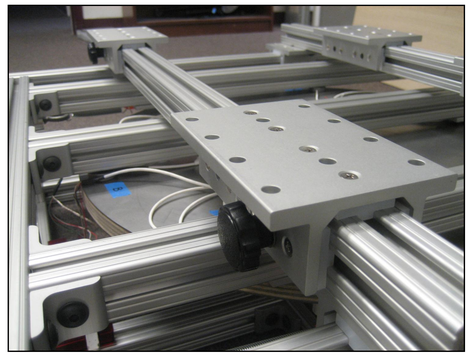
• Record and monitor the angular position as a function of time

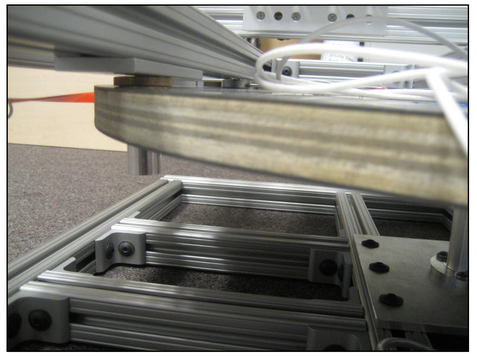
• Determine the average period of oscillation

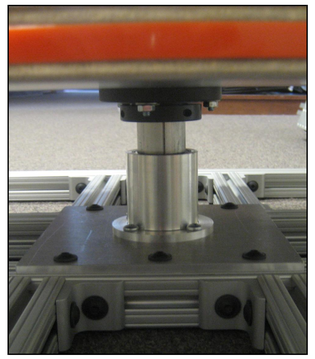
• Calculate the moment of inertia about the vertical axis using system dynamics

Design and Analysis









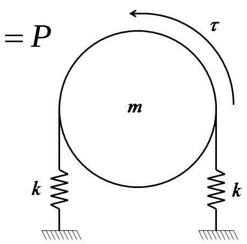
System Dynamics

• Equation of motion: $I\ddot{\theta} + k_{\text{eff}} R\theta = \tau$

• General form of the equation: $\ddot{\theta} + \omega_n^2 \theta = P$

• Natural frequency: $\omega_n = \sqrt{\dfrac{k_{\text{eff}} R}{I}}$

• Oscillation period: $T = \dfrac{2\pi}{\omega_n}$



• Moment of inertia can be calculated from

$$\therefore \quad I = \frac{k_{\text{eff}} R T^2}{4\pi^2}$$

Structural Design

• Frames made from extruded aluminum (80/20 Inc.) for ease of design and assembly

• Linear bearings allow x-y positioning for axial alignment of the shaft with the center of mass

• Spring-loaded disk made from thin steel plates glued to either side of sanded plywood

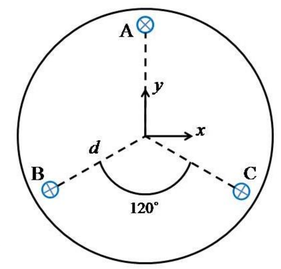
• Two bearings mounted inside the bottom shaft collar to minimize deflection and withstand 300 lb eccentric load applied at the end of the platform

Load Cell Analysis

• *N+1* load cells required to specify location in *N* dimensions

$$\Sigma M_x : -F_A d + F_B d \sin 30 + F_C d \sin 30 = mgY$$
$$\Sigma M_y : -F_B d \cos 30 + F_C d \cos 30 = mgX$$
$$\Sigma F_z : F_A + F_B + F_C = mg$$

$$\therefore \quad X = \frac{(F_C - F_B) d \cos 30}{F_A + F_B + F_C}; \qquad Y = \frac{[F_A - (F_B + F_C)\sin 30] d}{F_A + F_B + F_C}$$



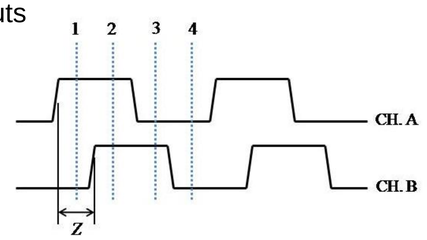
Encoder Analysis

• 2 channel quadrature TTL squarewave outputs

• Resolution:

$$Z = 90^\circ \text{e}\left[\frac{1\,\text{cycle}}{360^\circ \text{e}}\right]\left[\frac{1\,\text{rev}}{2500\,\text{cycles}}\right]\left[\frac{360^\circ}{1\,\text{rev}}\right] = 0.036^\circ$$

• Use 4X quadrature counting to track angular position as a function of time



Future Work

• Finish iMachine assembly

• Conduct validation tests for objects with known mass properties

• Begin testing manual wheelchairs for AMPS project

• Identify potential sources of error and develop a thorough error propagation analysis

Acknowledgements

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For more information, please visit
www.mobilityrerc.gatech.edu